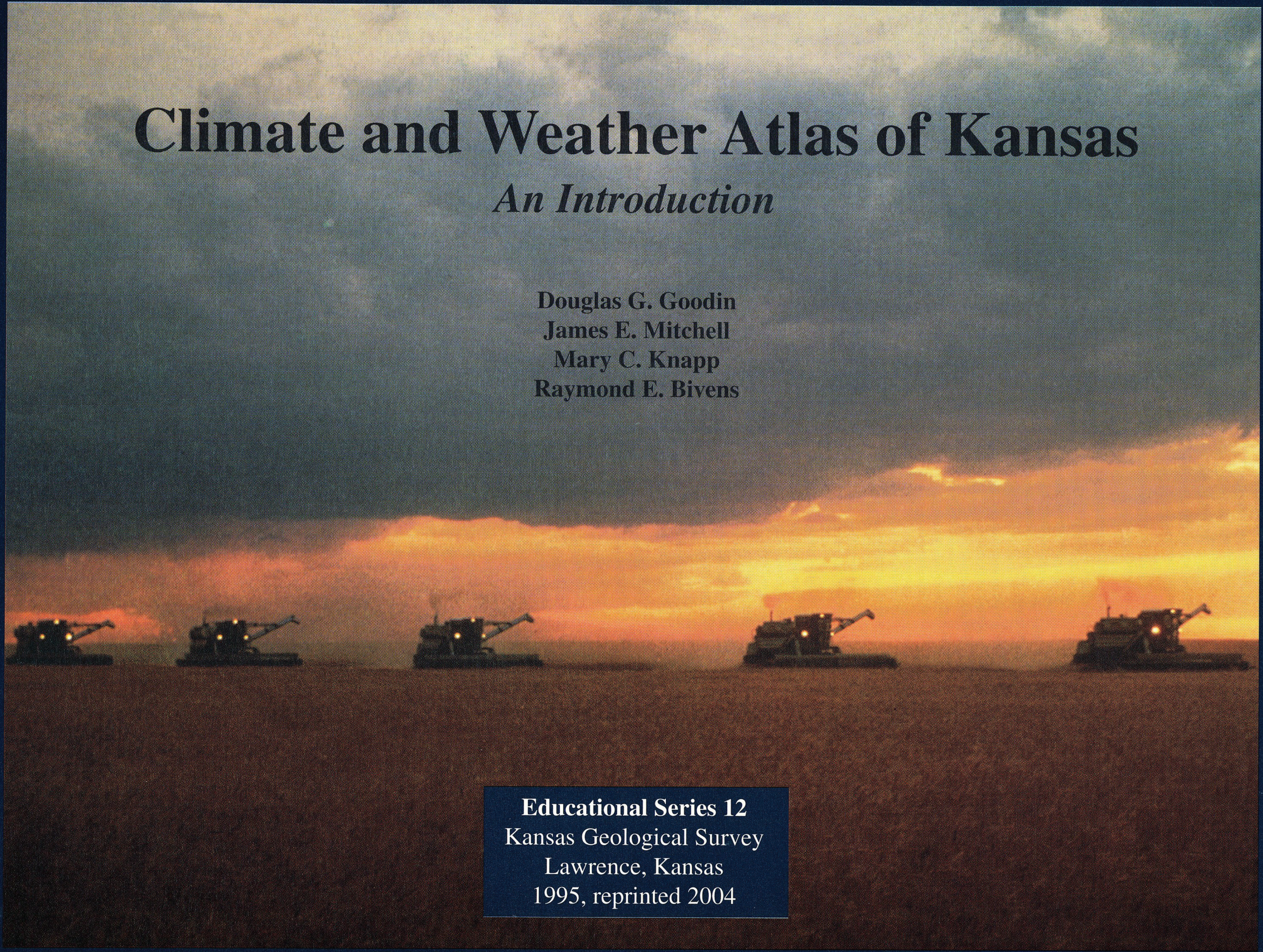
Climate and Weather Atlas of Kansas

An Introduction

Douglas G. Goodin
James E. Mitchell
Mary C. Knapp
Raymond E. Bivens



Educational Series 12
Kansas Geological Survey
Lawrence, Kansas
1995, reprinted 2004

Climate and Weather Atlas of Kansas

An Introduction

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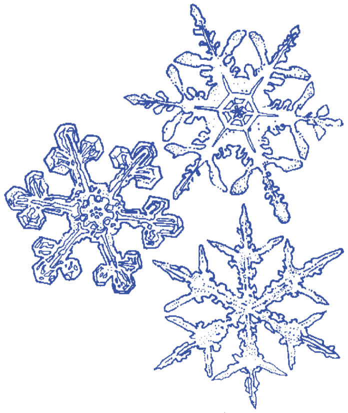

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INTRODUCTION

Because Kansas lies in the center of the continental United States, it is subject to varying weather patterns as air masses move across the state. Much of the severe weather for which Kansas is often noted is due to weather patterns that bring cold dry air into contact with warm moist air. Despite this reputation, the Kansas climate is partly responsible for the fertile soils and world-renowned agricultural industry.

Weather is an important part of our daily lives. We look to the paper, on radio and TV, and more recently on computer networks. Sites on the Internet or World Wide Web provide regional climate and weather information updated on a daily basis. This document is intended to give the general public information about some of the common terms and measurements they encounter in daily life. It cannot be used to plan daily activities, but provides an overview of the recorded weather and climate of Kansas. For example, this document includes maps of the first and last frost-free days across the state. This information would be of interest to gardeners in planning their activities. Or, it might be used to plan when to go camping or fishing. It would be of no use determining whether to wear a coat on a particular day.

This book is intended to provide basic information on the weather and climate of Kansas. The information is presented as a series of maps of selected climate and climate-related indices that are commonly reported in the media. All the information is derived from data collected across the state and compiled at the State Weather Library at Kansas State University. For more information about these data, the collection of the data, access to real-time computer information, or other aspects of the weather and climate of Kansas, contact the State Climatologist at:

State Climatologist
Weather Data Library
211 Umberger Hall
Kansas State University
Manhattan, KS 66506-3400

Phone: (785) 532-7019

FAX: (785) 532-6487

Electronic mail: wdl@oznet.ksu.edu

READING THE MAPS

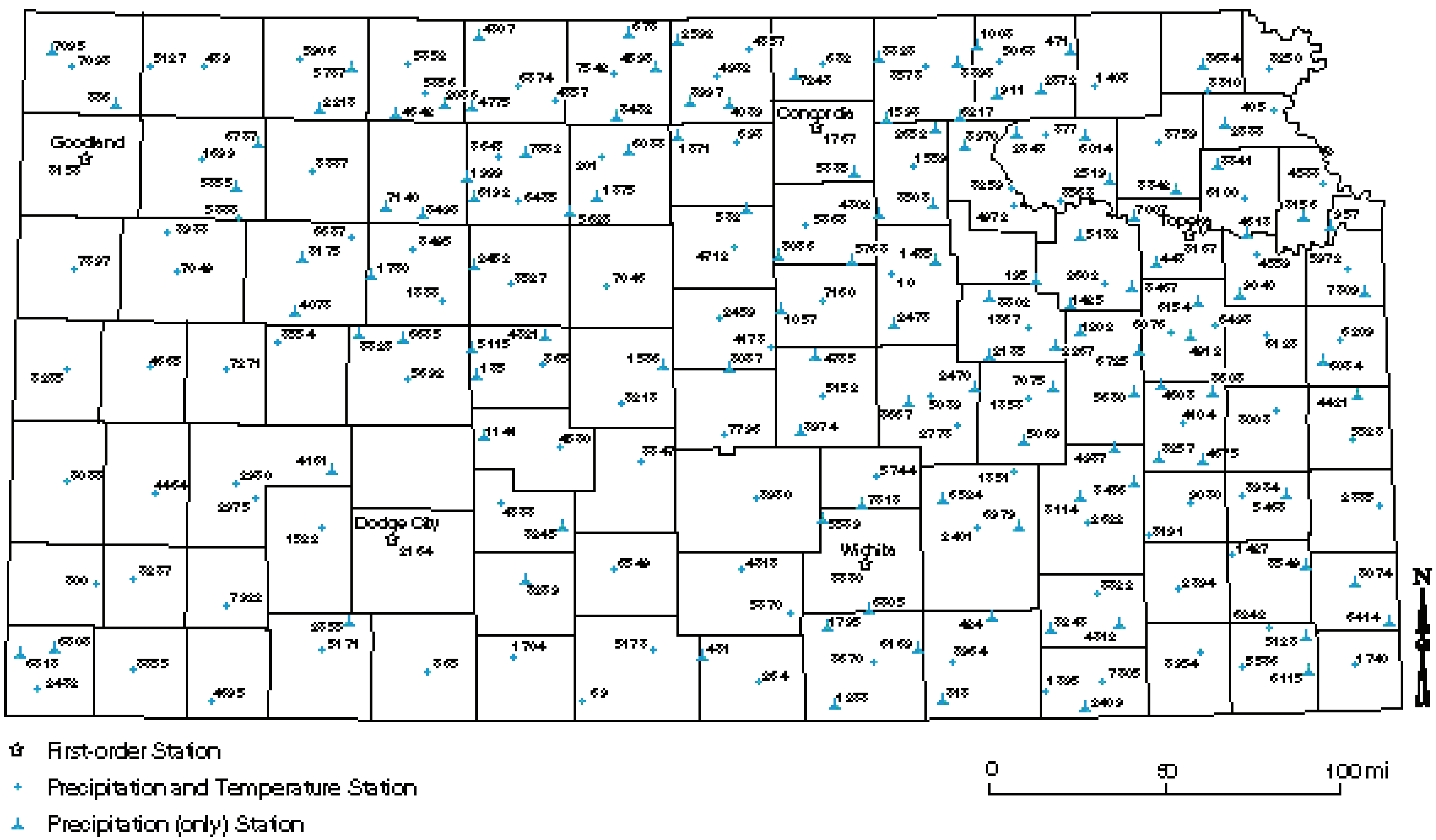
The various measures of climate in this book are displayed using contour maps. A contour map portrays information with a series of lines that each represent a single value. For example, the map of precipitation shows lines for 15 inches, 20 inches, etc. The interval between these contour lines can be said to receive 15 to 20 inches of precipitation per year. In general, as one moves from the 15-inch line toward the 20-inch line, one expects to observe increasingly higher annual precipitation. As successive lines are crossed west to east, higher values are expected. The shape of the line helps to display the pattern of precipitation across the state.

Although the maps display a clear representation of the general pattern of the various measures of climate, they are derived from weather stations scattered across the state (see map, page 1). Because of this, the process of contouring is an attempt to interpolate or predict the values between measured points. Various methods are used to interpolate contours.

None of the methods used for creating contour maps is exact or 100% perfect. Nevertheless, they are useful in depicting the general pattern of behavior across a region. Readers should keep in mind that the maps in this book are intended for just that purpose. They are not intended to be used for site-specific purposes or weather predictions. However, they can be a useful general guide for persons interested in average or normal values of the various measurements and indices.

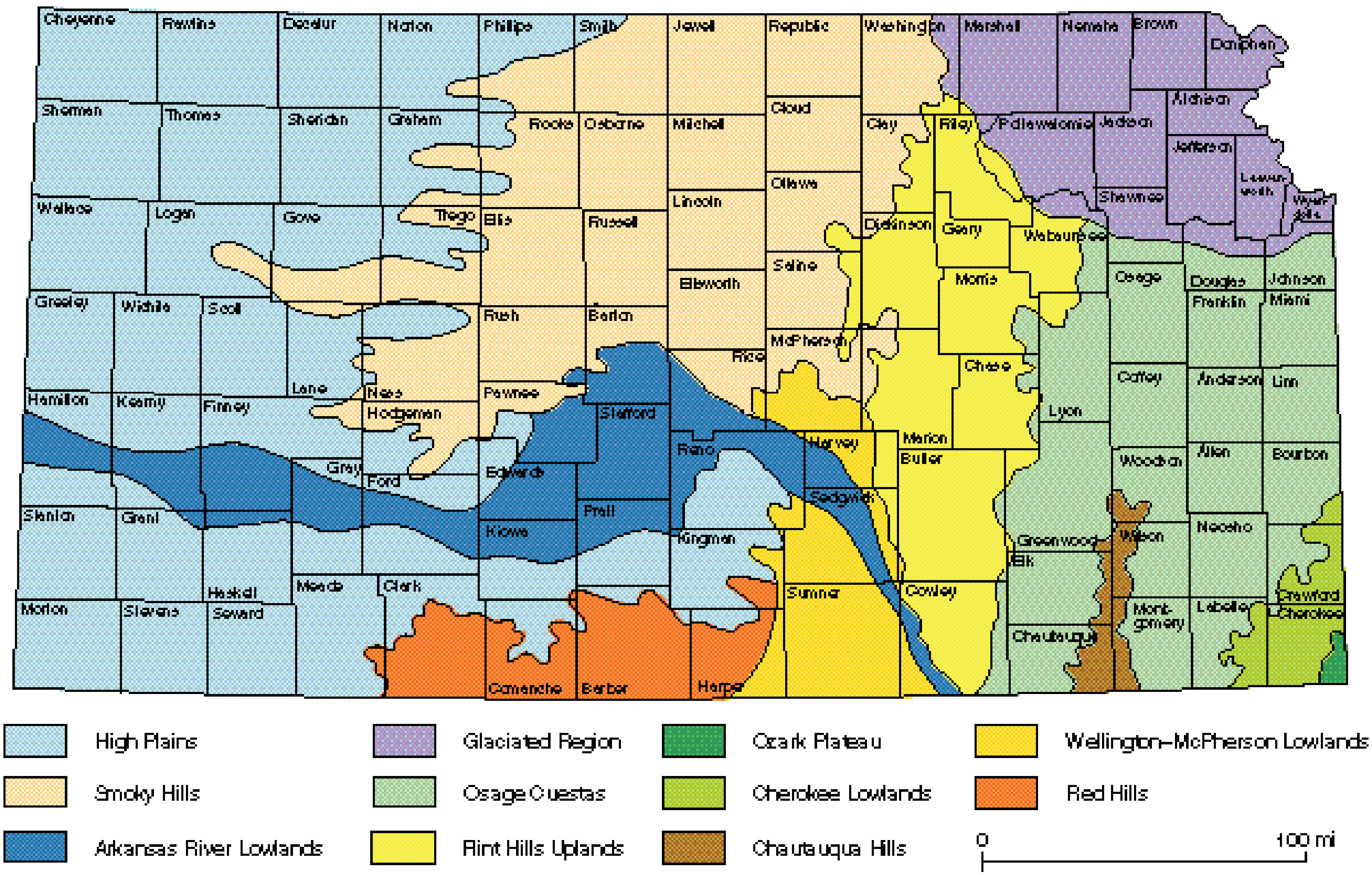
Station Locations

This map shows the location of the measurement stations where the data used in this atlas were collected. The five stations indicated by stars are first-order stations operated by the National Weather Service. These stations use very accurate instruments and have been in operation for the longest period of time. The other stations are part of the National Weather Service Cooperative Observer Network. These stations are operated by volunteer observers, who agree to maintain the site and instruments, as well as record, tabulate, and report the data. The cooperative network is designed to provide the most extensive coverage possible. At least one cooperative station is in operation in every county except Hodgeman. Station-location names are listed on pages 21–22.



Generalized Physiography and County Names

In order to make the climate maps easier to read, county names and major features are omitted. However, because county names are referred to in the text, they are included on this map in order to provide a reference to the reader. This map also divides the state into physiographic regions, or areas of similar land forms, such as hills or plains. The relationship between these regions and climate is discussed on page 19.



Generalized Physiography of Kansas

ANNUAL NORMAL PRECIPITATION 1961–1990

The amount of precipitation (rain and snow) is one of the most important factors in determining the agricultural productivity of Kansas. The map below shows the distribution of precipitation across the state, based on averages calculated over 30 years between 1961 and 1990. Darker tones indicate greater average annual precipitation, while lighter tones denote lesser amounts.

When studying the patterns of precipitation depicted on this map, it is important to remember that the contour lines depict averages, and the chances of any single year having exactly average precipitation are slight. Most years will deviate somewhat from the average. In some parts of the world, such as tropical rain forests, the yearly deviations will not be great; however, in the Great Plains of central North America, deviations from average are often rather large. Also bear in mind that the process of averaging over several years "evens out" the distribution of precipitation both in time and space. In reality, individual precipitation "events" (episodes of rain or snow) are more likely to occur over limited geographical areas, and at certain times of year. In Kansas, about 70–75% of all precipitation falls during the six crop-growing months from April to September. Most of this precipitation is in the form of rainfall accompanying small but intense thunderstorms. At other times of the year, precipitation is less common and more likely to occur as gentler rain or snow showers.

Measurement of Precipitation

The methods used to measure precipitation vary, depending on whether rain or snow is being measured. Rainfall is most often measured using a standardized gauge which resembles an upright cylindrical canister with an opening at the top. During a rainfall event, the opening catches water, which is conducted into a funnel-like device and then into a cylindrical measuring tube. Not all rain gauges are of this type, however. In fact, any container can be used as a rain gauge as long as it has a cross section with a consistent shape and size. Some gauges automatically record rainfall amounts, but most require an attendant who manually records precipitation amounts and empties the gauge prior to the next precipitation event.

Although the principle behind the rain gauge is simple, proper exposure of the gauge is critical for making accurate measurements. The opening must not be obstructed by any object which could prevent rain from falling into the gauge. Because rainfall is often diagonal, the gauge must also be kept away from buildings, high trees, or other objects that can shield the gauge. Ideally, the gauge should be positioned on the ground near the center of a large open area. The opening of the gauge should be high enough to prevent water from splashing into it during very heavy rains. Rain gauges are often fitted with a shield to reduce the effects of wind.

Determining the amount of precipitation resulting from snowfall requires measuring both the depth and water content of the snow. Water content of snow varies considerably. A frequently used rule-of-thumb states that 10 inches of snow contains 1 inch of liquid water, although the actual ratio can vary from 4:1 to as much as 30:1. Snow measurements are converted to precipitation amounts simply by melting a known amount of snow. Like measuring rainfall, measurement of snow is conceptually simple but difficult in practice. Often, measurements of snow depth are made simply by selecting a flat site and measuring the depth with a calibrated scale, such as a ruler or yard stick. Finding a representative site can be difficult, however. Even light to moderate winds can cause snow to drift, affecting the accuracy of measurements. Usually, the

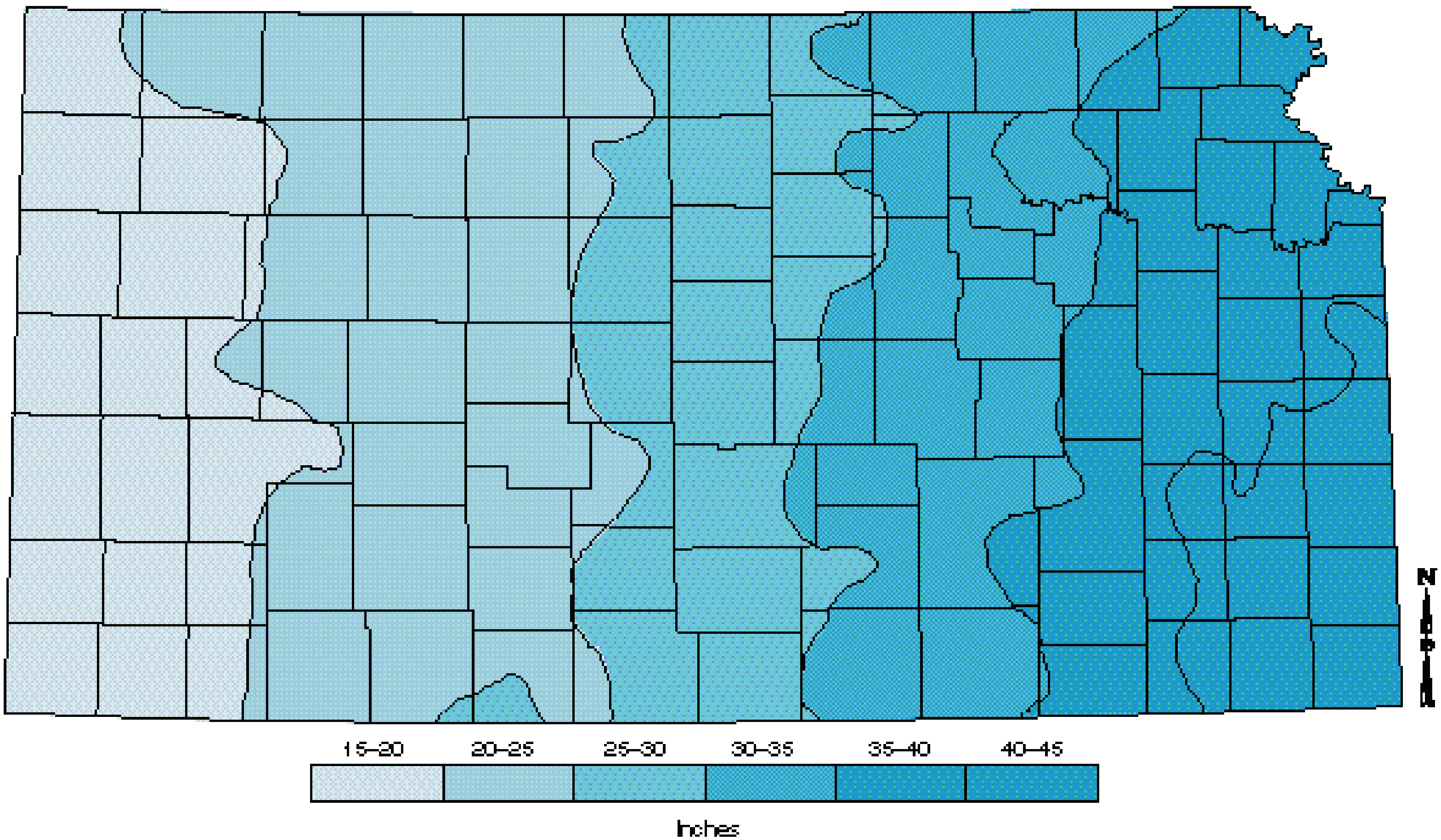
Record-breaking Incidents of Precipitation for Selected Cities (measured in inches):

City (County)	Rainfall	Snowfall
Ashland (Clark)	6.52 (October 1920)	16.0 (December 1911)
Colby (Thomas)	4.50 (July 1941)	14.0 (February 1924)
Columbus (Cherokee)	8.40 (June 1948)	17.5 (December1917)
Elkhart (Morton)	6.80 (July 1911)	20.0 (February 1903)
Emporia (Lyon)	7.03 (November 1928)	11.0 (February 1900)
Hays (Ellis)	5.26 (September 1955)	12.0 (February 1903)
Horton (Brown)	7.15 (October 1973)	14.0 (February 1955)
Independence (Montgomery)	7.69 (May 1984)	19.0 (March 1970)
Manhattan (Riley)	6.28 (June 1977)	18.0 (February 1900)
McPherson (McPherson)	4.37 (August 1980)	20.0 (February 1912)
Medicine Lodge (Barber)	9.00 (September 1923)	14.0 (February 1971)
Minneapolis (Ottawa)	6.34 (September 1942)	14.0 (February 1980)
Ottawa (Franklin)	6.95 (November 1928)	14.0 (March 1912)
Phillipsburg (Phillips)	7.50 (September 1919)	16.0 (November 1953)
Tribune (Greeley)	6.46 (June 1932)	18.0 (March 1987)
Winfield (Cowley)	9.12 (October 1973)	12.0 (February 1938)

average of several measurements taken in a flat area away from trees or structures is used. Sometimes, snow gauges consisting of large cylindrical tubes are used. As with rain gauges, these snow gauges are shielded to reduce the effects of wind. Mean annual snowfall is shown on page 5.

Precipitation Patterns in Kansas

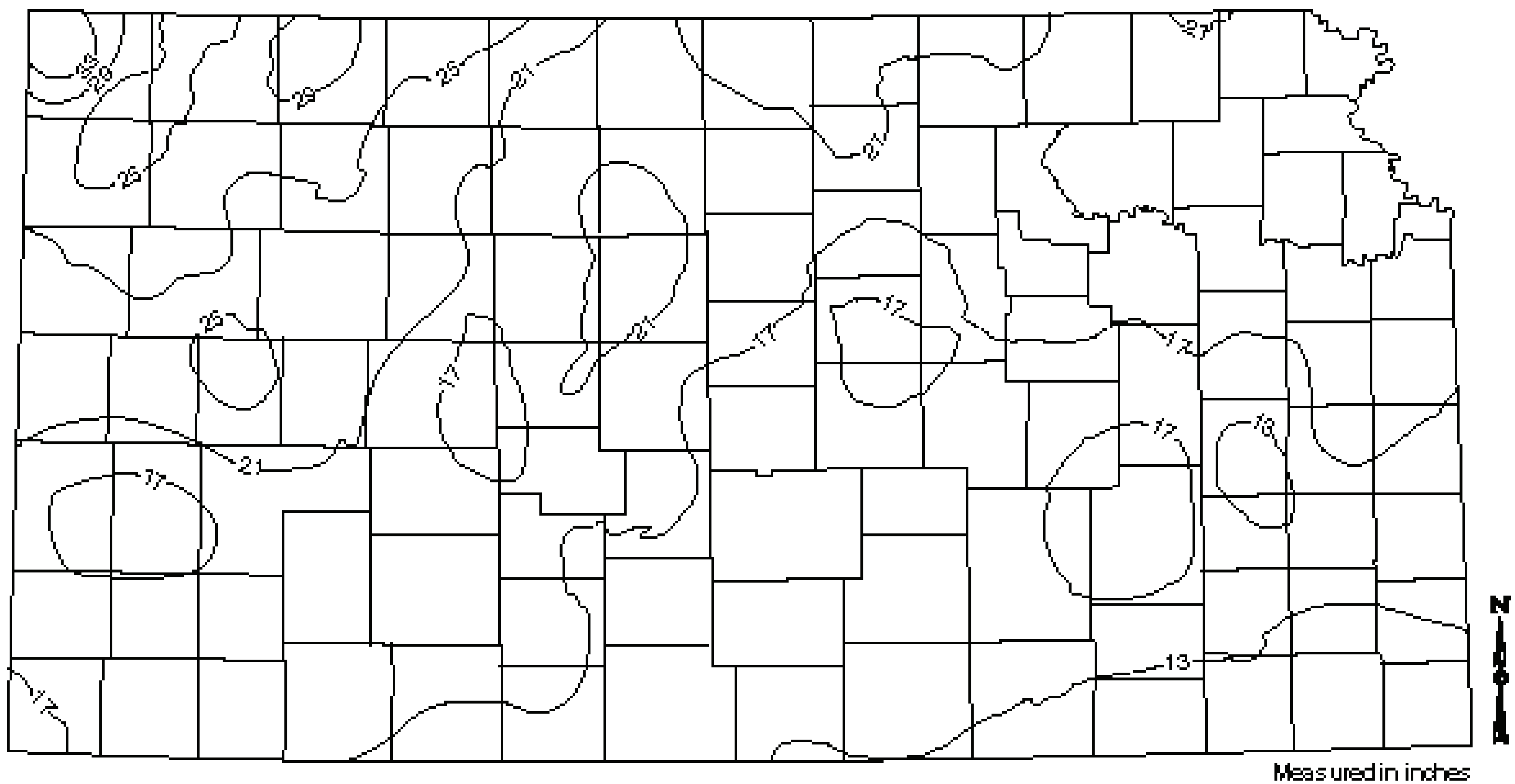
The pattern of precipitation shown on the map indicates a very large contrast in precipitation amounts across the state. Yearly precipitation amounts along the western border are only one-third of those in the southeast corner of the state. These large variations between east and west are typical of the Great Plains region of central North America, where the climate is transitional between the humid east and the semi-arid and arid western portion of the continent. This transitional pattern greatly affects agricultural



Normal Annual Precipitation

practices within Kansas. West of the so-called "25-inch line," which nearly divides the state in half, surface water is often in short supply. Irrigation systems that draw water from underground are frequently necessary to produce most cereal and grain crops.

The reasons for the large contrast in precipitation amounts from east to west are related to the location of Kansas in the heart of the North American continent. The Rocky Mountains, which lie to the west, block the eastward flow of moisture-laden air from the Pacific Ocean, creating a "rainshadow" of low precipitation. As the air rises over the mountains, it loses its moisture content through precipitation. By the time these airflows reach western Kansas, their moisture content is decreased, so they produce little precipitation in the western part of the state. In contrast, eastern Kansas frequently receives incursions of very moist air from the Gulf of Mexico, particularly during the spring and early summer seasons. This warm, moist air mixes with colder, dry air from the north, producing the intense storms that are so common in eastern Kansas during the spring and early summer. These two mechanisms combine to produce the very large contrast in precipitation within the state of Kansas.



Mean Annual Snowfall

Along with precipitation, temperature is a basic element of the climate of a region. Temperature is of great significance not only to human comfort and well-being, but also to agricultural productivity. The production of cereal grains forms the basis for the agricultural economy of Kansas, and the yearly pattern of temperatures is an important influence on both where and when various crops can be produced.

How Temperature Measurements are Made

Most temperature measurements are made with the familiar mercury-in-glass thermometer. This thermometer works on the principle that most substances expand when heated. Mercury is used because when heated, it expands much more than glass and, when cooled, it contracts more than glass. Because of this difference in relative expansion, the length of the column of mercury in a glass tube can be used as a measure of surrounding temperature. A calibrated scale is placed on or next to the glass tube so that the temperature can be read easily.

The simplest and most common type of thermometer is designed to show the current temperature. The mercury is contained in a small, bulb-like reservoir at the bottom of a glass tube. The mercury column in the tube rises or falls in response to temperature change, its length always indicating current temperature. Other thermometers are specially designed to indicate minimum and maximum temperatures. A maximum thermometer is similar to the mercury thermometer described above, except that a constriction is placed in the tube, near the reservoir. As temperatures increase and the mercury expands, it is forced past the constriction and rises into the tube, but when temperatures fall, the constriction does not allow the mercury column to fall back into the bulb. Thus, the temperature indicated by the mercury will always be the maximum daily temperature. The maximum thermometer is reset by shaking or whirling it to force the mercury column past the constriction and back into the reservoir.

In contrast to the maximum thermometer, the minimum thermometer contains a low-density liquid, usually alcohol. A small, dumb-bell shaped index is placed within the tube so that it touches the top of the alcohol column. As temperature decreases, the alcohol contracts and the index is pulled toward the reservoir by the effect of surface tension with the top of the alcohol column. When temperatures rise, however, the alcohol can flow around the index without moving it. The index will therefore always remain at the point of the lowest temperature. The minimum thermometer is reset by tilting to return the index to the top of the alcohol column. Because the index is free to move, the minimum thermometer must always be mounted horizontally.

Temperature measurement depends not only on accurate thermometers, but also on proper exposure of the thermometer to air. Thermometers must be kept away from sources of radiant energy, because the instrument itself will absorb the radiation and heat up, affecting the accuracy of measurements. Thermom-

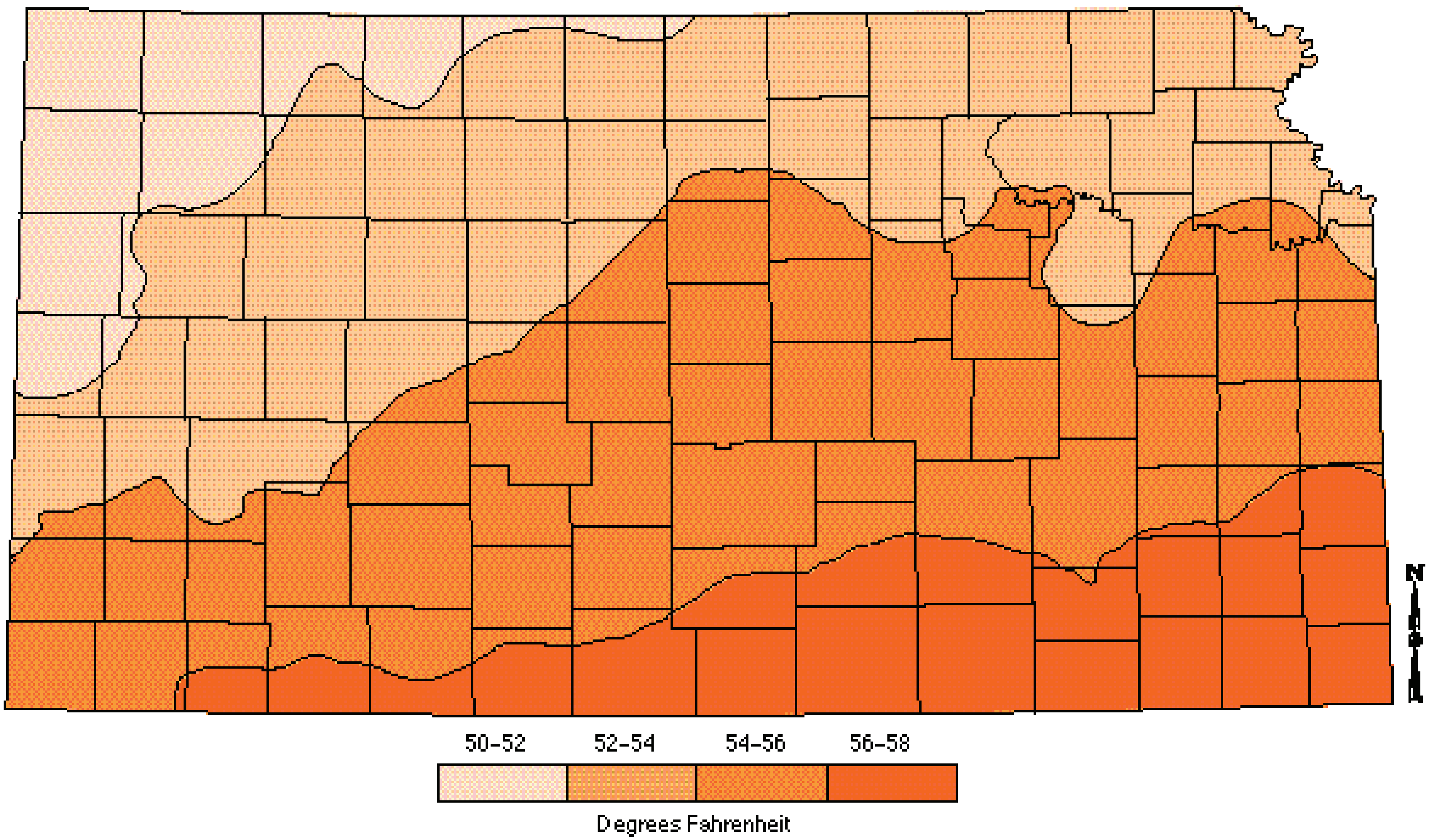
Record-breaking Temperatures for Selected Cities (measured in °F):

City	Highest Temperature	Lowest Temperature
Ashland (Clark)	114 (June 1911)	-19 (January 1988)
Colby (Thomas)	113 (July 1940)	-28 (January 1912)
Columbus (Cherokee)	117 (July 1954)	-28 (February 1905)
Concordia (Cloud)	109 (July 1980)	-26 (December 1989)
Dodge City (Ford)	109 (July 1986)	-21 (December 1989)
Elkhart (Morton)	110 (June 1980)	-22 (January 1984)
Emporia (Lyon)	116 (August 1936)	-24 (January 1947)
Goodland (Sherman)	111 (July 1940)	-27 (December 1989)
Hays (Ellis)	117 (July 1934)	-26 (February 1905)
Horton (Brown)	112 (August 1936)	-30 (January 1947)
Independence (Montgomery)	116 (August 1936)	-23 (February 1905)
Manhattan (Riley)	116 (August 1936)	-31 (January 1947)
McPherson (McPherson)	117 (August 1936)	-22 (January 1963)
Medicine Lodge (Barber)	118 (August 1936)	-22 (February 1905)
Minneapolis (Ottawa)	119 (August 1936)	-28 (February 1905)
Ottawa (Franklin)	118 (July 1954)	-28 (February 1905)
Phillipsburg (Phillips)	120 (July 1936)	-28 (December 1989)
Topeka (Shawnee)	110 (August 1984)	-26 (December 1989)
Tribune (Greeley)	108 (July 1936)	-25 (January 1984)
Wichita (Sedgwick)	113 (July 1954)	-21 (February 1982)
Winfield (Cowley)	118 (August 1936)	-27 (February 1905)

eters should therefore be shielded from direct sunlight, as well as from surfaces that radiate heat such as buildings and the ground. Good ventilation is also important, because stagnant air around the thermometer will not represent true air temperature. The height at which air temperature is measured and the surface over which the measurements are made can also have significant effect on measured values. Whenever possible, thermometers are placed in a louvered white wooden box at a height of about one meter, preferably over a grass surface far away from buildings. Such a shelter protects the thermometer from solar radiation, while allowing air to circulate freely around the thermometer.

Temperature Maps

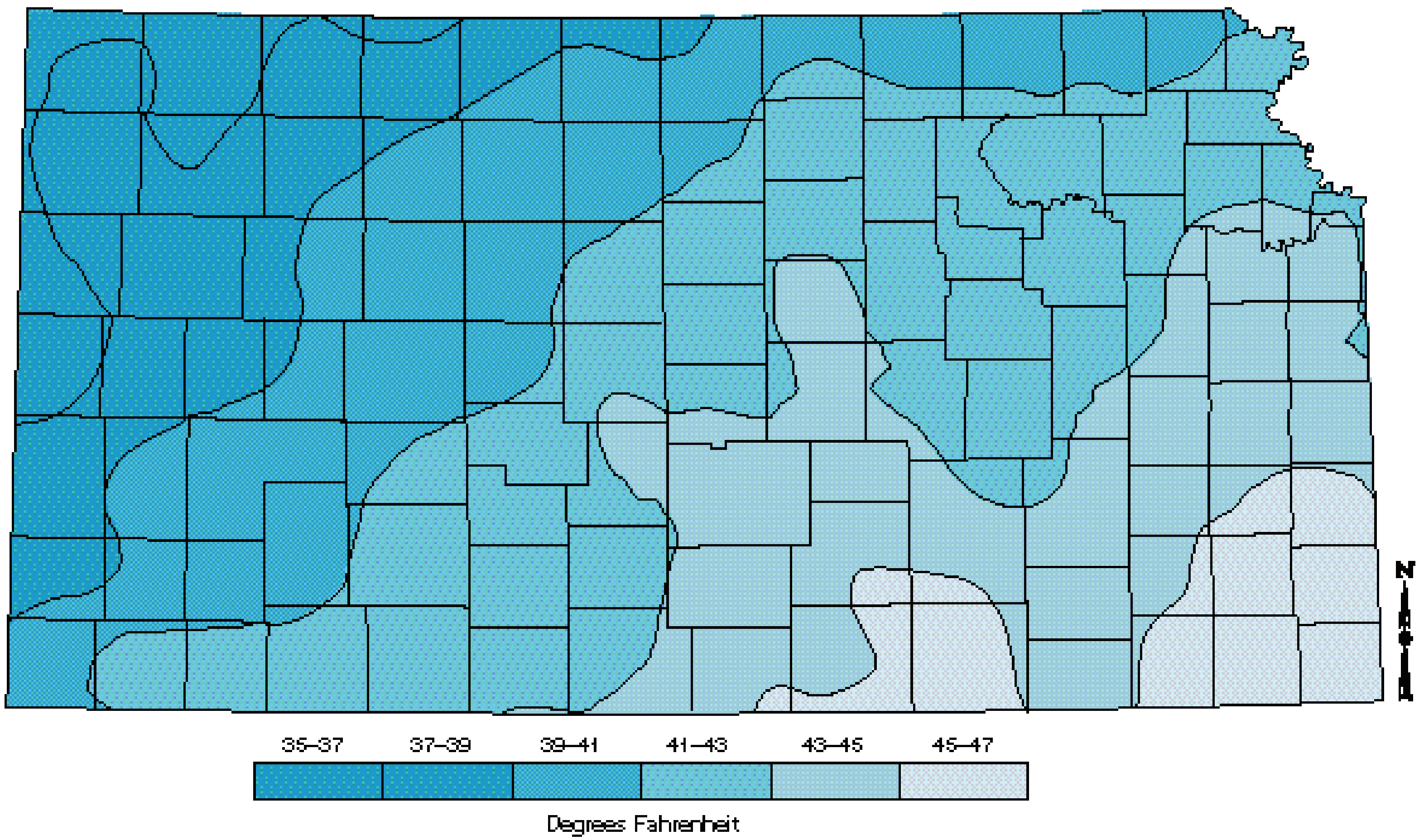
On the following pages, maps depicting various types of temperature information are presented. The data for these maps were obtained from the temperature-measurement sites shown on the map on page 1. Some of the measurement sites were not used in making these



Average Annual Mean Temperature

maps, however. Any measurement site located near a body of water (such as a dam site) was eliminated because water heats and cools much more slowly than the surrounding land, affecting nearby air temperatures and producing temperature measurements that are not representative of the surroundings. The time of day at which temperatures are recorded can also greatly influence minimum and maximum values. At most (but not all) stations, observations are taken at midnight. To ensure consistency in the maps, readings from those stations which were not recorded at midnight were adjusted using a formula developed by the National Climatic Data Center in Asheville, North Carolina.

Temperature varies considerably over the course of a year, making it difficult to adequately summarize using a single map. Seven maps are used to provide a more complete description of temperatures in Kansas. The temperature data on the maps are presented in the form of "means," which is a term used by scientists to indicate an average. Thus, average annual mean temperature (shown on the first map) is the average of all the yearly averages in the 30-year period from 1961 to 1990. Similarly, the mean minimum and maximum

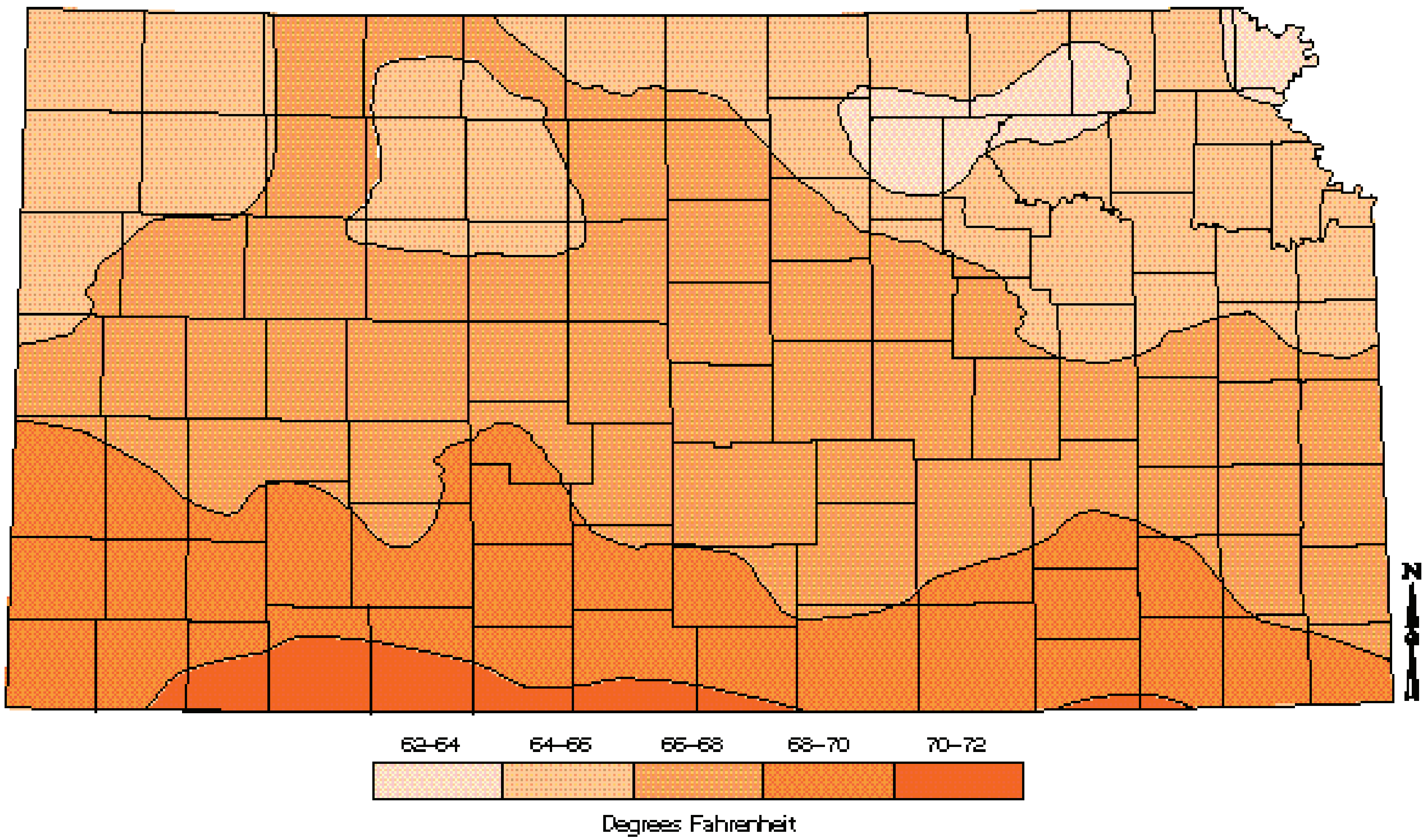


Mean Annual Minimum Temperature

temperatures (depicted on the next two maps) are the average of minimum and maximum values for each year. Mean temperatures for each individual season are shown on the next four maps.

When viewing the maps, it is important to remember that the conditions in any given year are quite likely to deviate from the mean conditions. This is especially true for areas such as Kansas that are located near the center of a continent. Conditions in Kansas can deviate quite widely from mean conditions; for example, a year or two of relatively low temperatures may be followed by a period of exceptionally hot weather.

The pattern of temperatures in all seven maps clearly shows the effect of latitude. Mean, minimum, and maximum values are greater in southern Kansas and decrease going northward. This trend within the state is actually part of a larger global pattern in which mean temperatures are greater nearer the equator and steadily decrease going toward the poles. This global pattern reflects the fact that incoming solar radiation (which provides the energy to heat the air) is much more intense near the equator and tropics compared to the higher latitudes. Notice also that the contour lines of temperature (called isotherms) do not run exactly east-

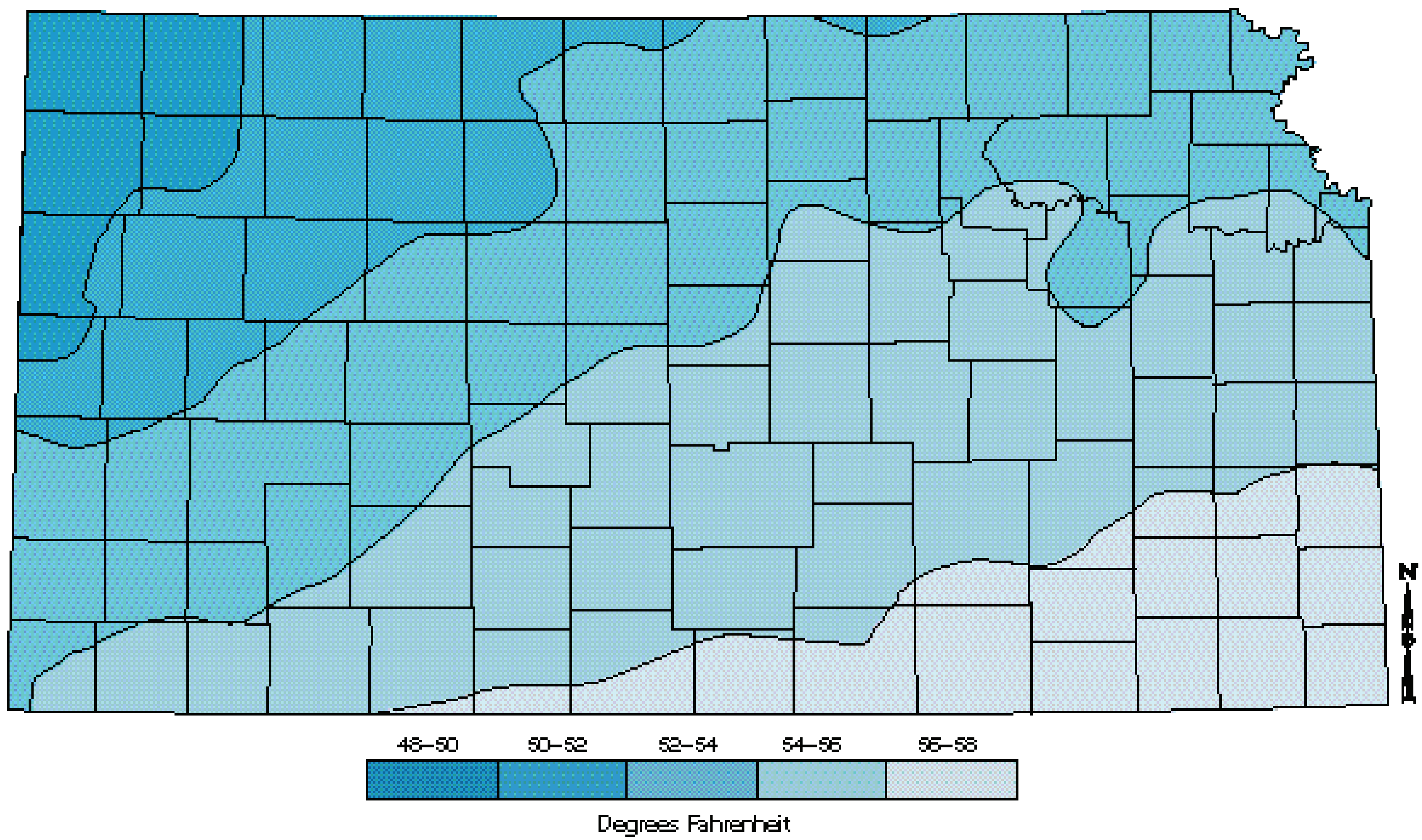


Mean Annual Maximum Temperature

west. Instead, they trend generally from the northeast to southwest. This pattern reflects another significant influence on temperatures—changes in elevation. In Kansas, elevations range from as low as 680 ft in southeastern Kansas to 4,039 ft in the west. Air temperatures decrease by about 2° to 3° for every 1,000 ft of altitude gained; therefore, mean temperature will be about 6° to 9° lower for the same latitude at the western border compared to the eastern border.

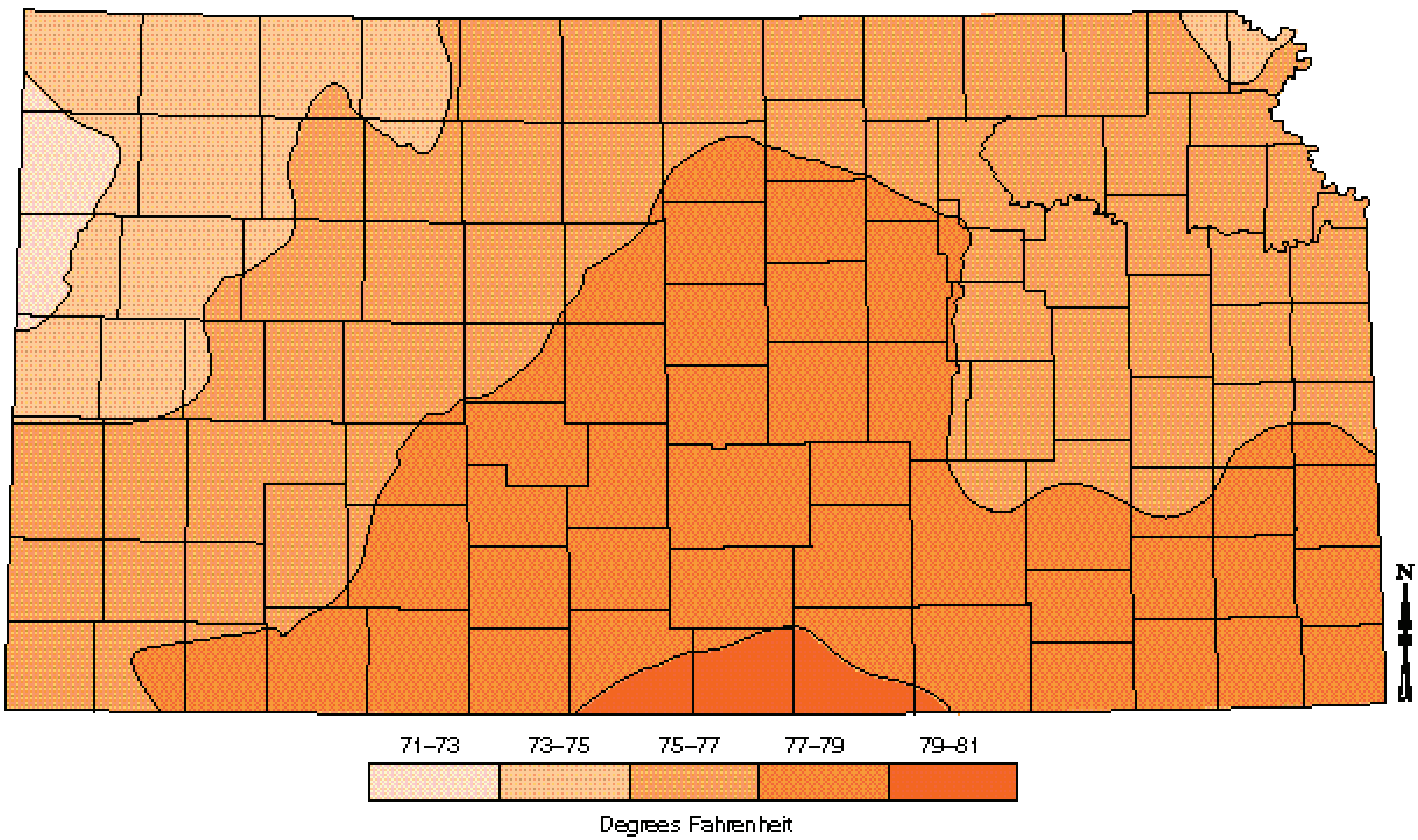
Seasonal Maps

When comparing the mean temperatures shown on the following four maps, notice the large seasonal contrast. In Kansas, the seasons are defined as follows: Spring (March–May), Summer (June–August), Fall (September–November), and Winter (December–February). Summertime temperatures are much greater than those in winter, fall, or spring (and vary greatly from the average annual mean temperature [page 7]). This may not seem especially noteworthy, but it reflects



Seasonal Mean Temperature—Spring

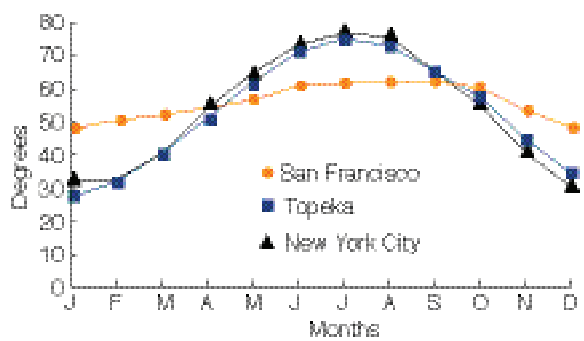
an important characteristic of Kansas climate. A climate such as that of Kansas, which shows these large seasonal temperature contrasts, is called a *continental* climate. As the name suggests, these climates occur in the interior of continents. In contrast, *maritime* climates are found in coastal areas or near large bodies of water. Maritime climates are characterized by very little seasonal temperature variation. The reason for the difference lies in the very different thermal properties of water versus land. Water is much more thermally conservative than land; that is, it heats up and cools off much more slowly when subjected to solar radiation. This resistance to temperature change means that air-temperature measurements for sites near bodies of water will generally not be as warm in summer nor as cold in winter as would an inland site at the same latitude. All bodies of water exhibit this influence over temperature, but the size of the surrounding area affected depends on the size of the water body. Recall that measurement sites near lakes were eliminated prior to constructing the temperature maps. The temperature measurements from these sites were unrepresentative even though they are near relatively small water bodies. A very large body of water, such as an ocean, can affect temperatures for hundreds of miles inland.



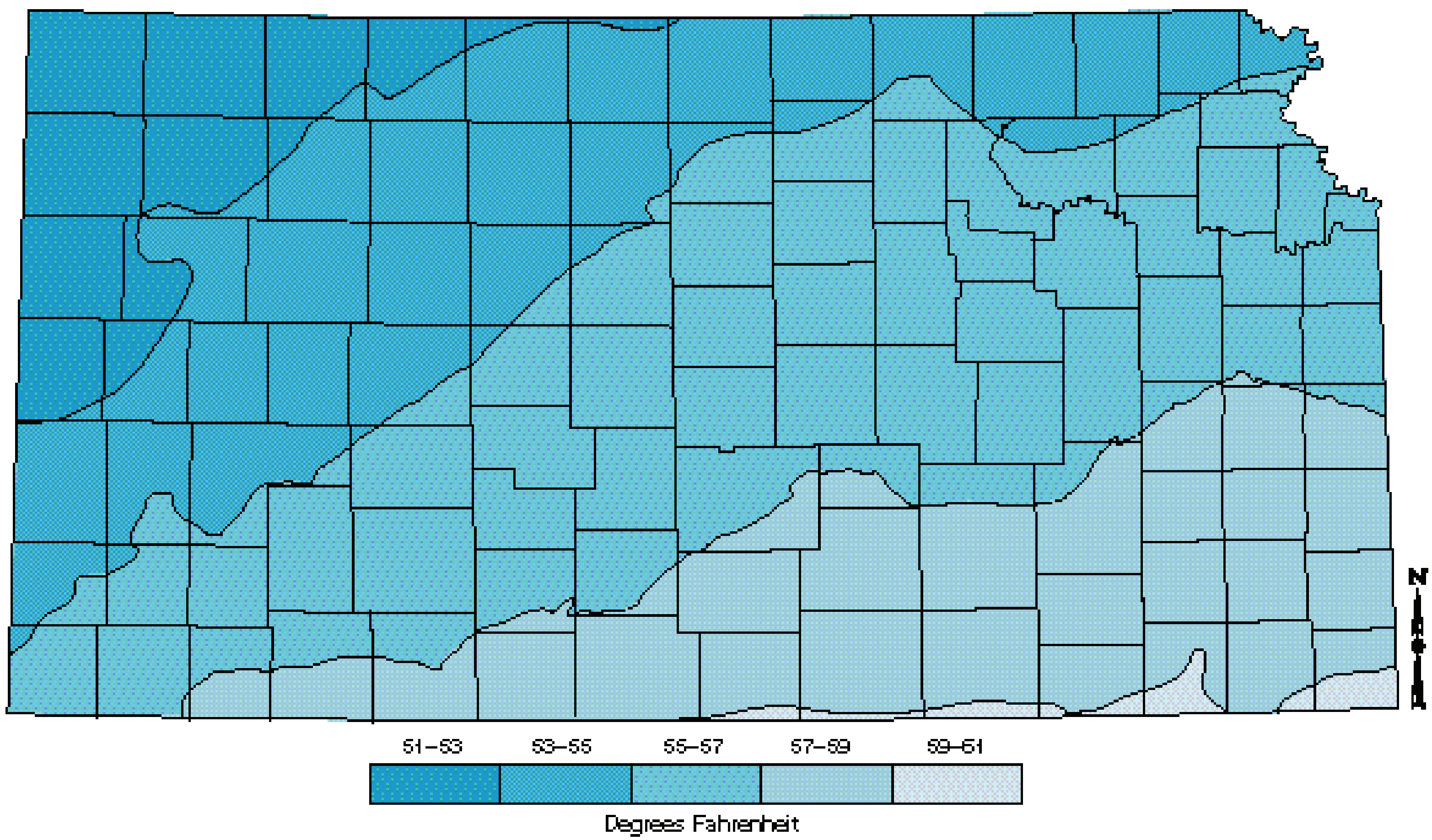
Seasonal Mean Temperature—Summer

The graph shown at right illustrates the idea of continentality by showing monthly mean temperatures for three sites in the United States which are all at approximately the same latitude. Notice that winters are much warmer and summers are cooler in San Francisco compared to New York City or Topeka. San Francisco is located near the Pacific Ocean, and thus features a maritime climate. New York City is also located near an ocean, but its yearly temperature

Continentality Illustrated by Monthly Mean Temperatures



Month	San Francisco	Topeka	New York City
January	48	28	32
February	51	33	33
March	53	41	41
April	55	55	52
May	58	65	62
June	62	74	72
July	63	78	77
August	63	77	75
September	64	68	68
October	61	58	59
November	55	43	47
December	50	32	36

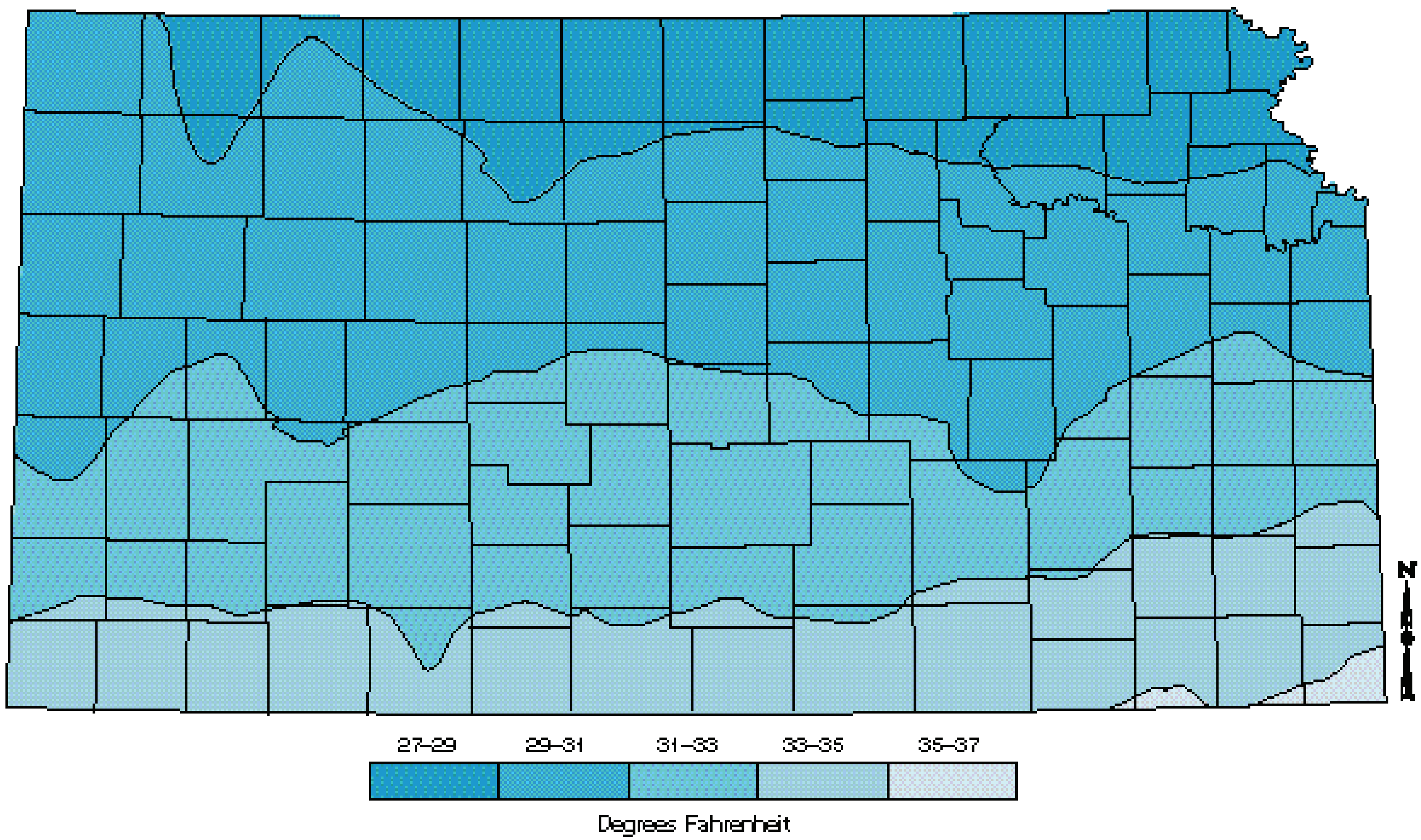


Seasonal Mean Temperature—Fall

pattern is much more typical of a continental region. In North America, weather patterns generally move from west to east. Therefore, the climate of New York City, located on the east coast, is much more influenced by the landmass to the west than the ocean to the east. However, variablity of temperatures in New York City is less than that in Topeka. San Francisco, situated on the west coast, receives the full influence of the ocean. Topeka, located near the center of the North American continent, is unaffected by either ocean and therefore exhibits marked seasonal variation.

Record-breaking Kansas Weather Incidents

Lowest temperature:		–40°F	Lebanon	February 13, 1905
Highest temperature:		121°F	Fredonia	July 18, 1936
		121°F	near Alton	July 24, 1936
Rainfall:	(single event)	12.59 inches	Burlington	March 31, 1941
	(annual)	71.99 inches	Hiawatha	1973
Tornadoes (avg/yr):		38		
Tornado deaths (avg/yr):		3		
Total lightning deaths (1959–1990):		55		
Deadliest tornado:		80 people killed	Udall	May 25, 1955
Other:	Largest hailstone recorded anywhere			
	1.67 pounds, 17.5-inch circumference		Coffeyville	September 3, 1970



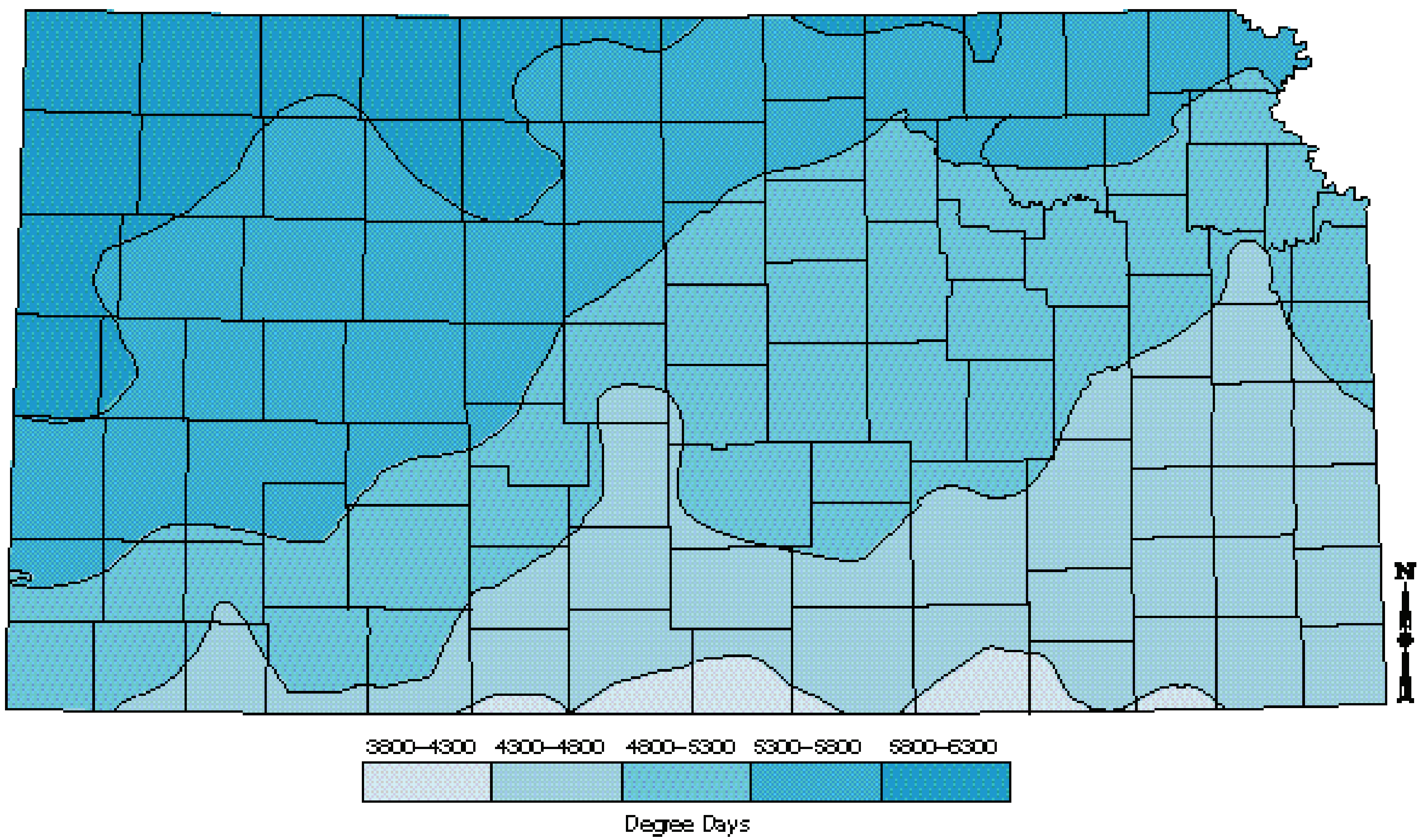
Seasonal Mean Temperature—Winter

Heating and Cooling Degree Days

Heating and cooling degree days are frequently used as an indicator of how much energy will be required to heat or cool buildings or residences. With current concerns for energy conservation and utility prices, engineers often take into account the annual average number of degree days when designing a building in a certain area.

How are Annual Average Degree Days Calculated?

Heating and cooling degree days are calculated based on the amount by which the daily mean temperature falls below or exceeds some accepted threshold temperature. In North America, the threshold temperature is generally 65°F (18°C). Heating degree days are calculated by determining how much the daily mean temperature falls below this threshold, while cooling degree days are figured by how much the daily mean temperature exceeds the threshold. Thus, if the mean temperature for a given day was 40°F, then heating degree days would be determined by subtract



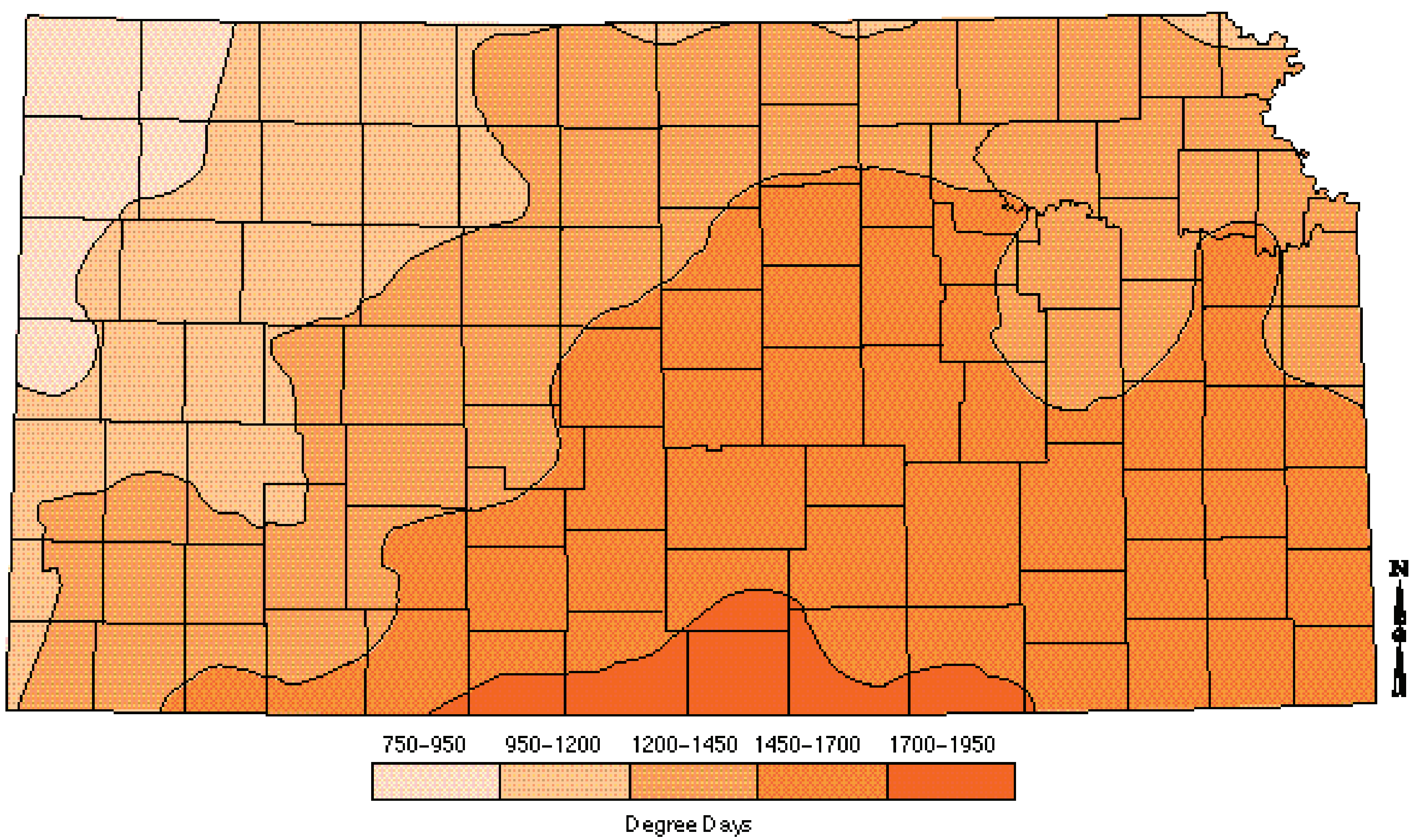
Mean Annual Heating Degree Days

ing 65 – 40 = 25 heating degree days. Similarly, if the daily mean temperature was 80°F, then cooling degree days would be determined by 80 – 65 = 15 cooling degree days. Notice that any given day can (and probably will) account for several heating or cooling degree days. Annual degree days are determined by simply summing the daily total values. The data depicted on these maps are the average sums of heating and cooling degree days for the thirty-year period between 1961 and 1990, and represent the total degrees of temperature per year that need to be heated (heating degree days) or cooled (cooling degree days) to maintain the 65°F target temperature.

Uses of Degree Days

Degree days have been proven to be among the most useful of all climate data for several practical applications. Architects and engineers consider the number of heating and cooling degree days when designing the air conditioning and heating systems of buildings. Fuel distributors often base their prices and delivery schedules on cumulative number of degree days. Utilities such as power companies use average degree-day data to try to anticipate power needs, and also to implement priority-use policies in cases where capacity falls short of demand.

Degree days also are useful for directly comparing energy costs for heating and cooling. Individual homeowners can use this information to make deci



Mean Annual Cooling Degree Days

sions on where to live and what energy costs will be at various locations. For example, a homeowner in Goodland, with about 6,200 heating degree days annually, can expect to pay higher heating bills than one in Topeka, where annual heating degree days average less than 5,000. However, the Topekan will generally pay higher costs for air conditioning, since Topeka averages around 1,300 cooling degree days per year, compared to less than 1,000 in Goodland. By comparison, a resident of International Falls, Minnesota (which averages only about 175 cooling degree days annually), will spend little or nothing for air conditioning, since 400 cooling degree days is generally considered the minimum for which air conditioning is needed to maintain comfortable temperatures. International Falls experiences over 10,000 heating degree days per year, however, so our Minnesotan can expect to pay over twice what a Topeka resident would pay for heating (provided, of course, that energy costs were the same per degree day at each location).

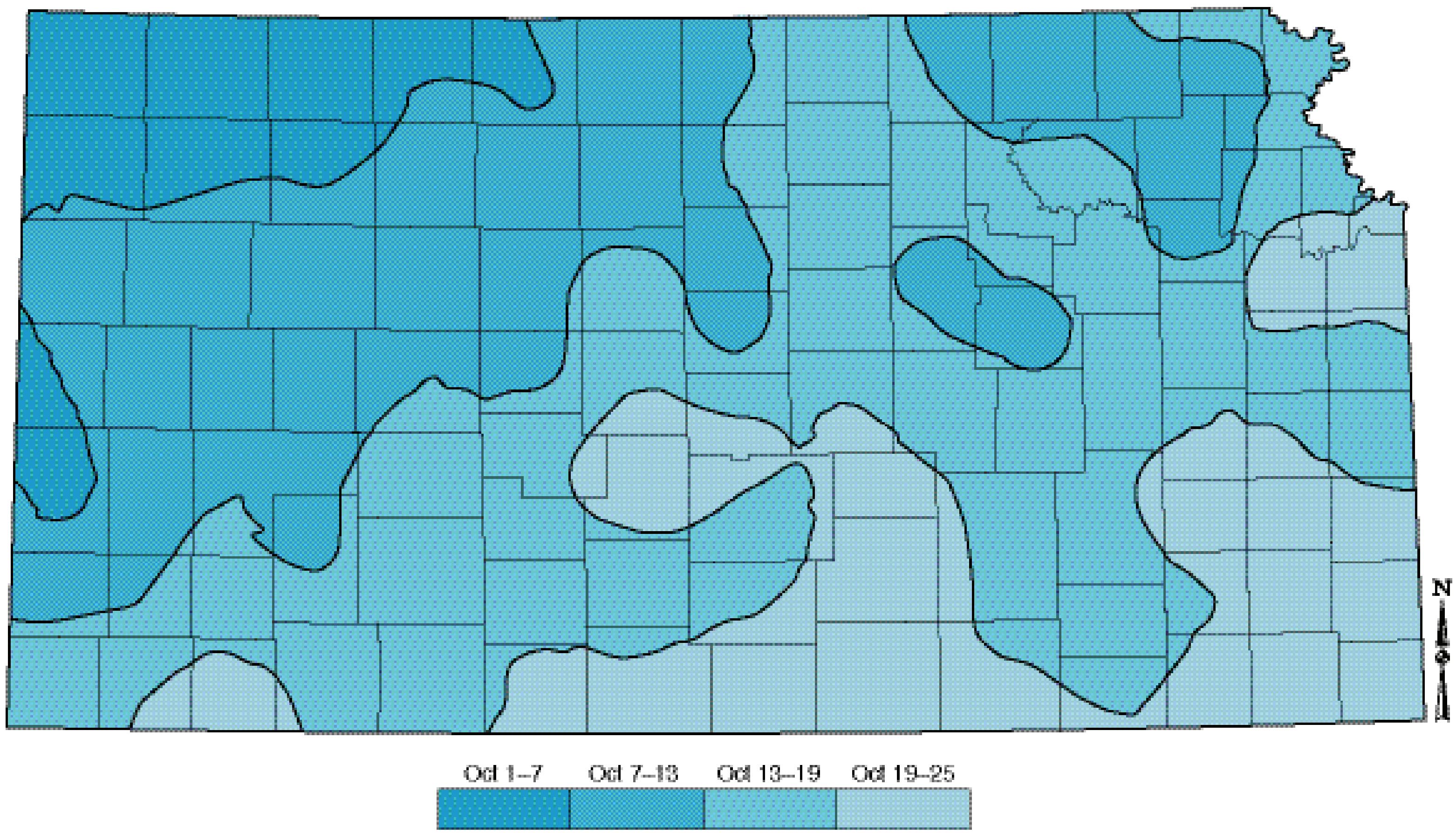
Patterns of Degree Days in Kansas

The pattern of both heating and cooling degree days in Kansas is directly comparable to that of the minimum and maximum temperature (see maps on pages 7 and 8). The trend of cooling degree days goes from higher values in the south to lower values in the north. Since cooling degree days are an indicator of heat, and temperatures are generally higher in southern Kansas, this pattern is consistent with temperature data. Heating degree days show a similar pattern, but in this case values are smaller in the south and get progressively larger going northward. This reflects the influence of temperature patterns, since a larger number of heating degree days indicates lower temperatures, and temperatures are generally lower in the northern part of the state. As were the isotherms, the contour lines of both heating and cooling degree days are oriented southwest to northeast, rather than north to south. Again, this reflects the influence of altitude on temperature distribution within the state (see the discussion of the temperature maps for further information).

Freeze Date

The following two maps show the average annual date of the first and last freeze. In these maps, a "freeze" is considered to be a period in which the temperature falls below 32° F, the freezing point of water. Although this may seem self-evident, other temperature thresholds, such as 28°F, are sometimes used to define a freeze. It is important to consider which definition of a freeze is being used. Two processes can result in a freeze. The most common process occurs when a very cold mass of air moves into an area, lowering the surface temperature below freezing. Climatologists call this an *advection frost*. Advection frosts are most common in Kansas during the winter months. The other type of freeze occurs on very clear nights. Without a layer of cloud cover to act as a blanket to hold heat, the surface can cool off very quickly. This type of freeze is called a *radiation frost,* because the ground radiates enough heat to lower its temperature below freezing temperatures. Ice crystals then form on cold objects at the surface. Of the two processes, the advection frost is the one most often associated with a true freeze.

Freeze dates are very significant for agricultural producers, because most crops grown in Kansas have

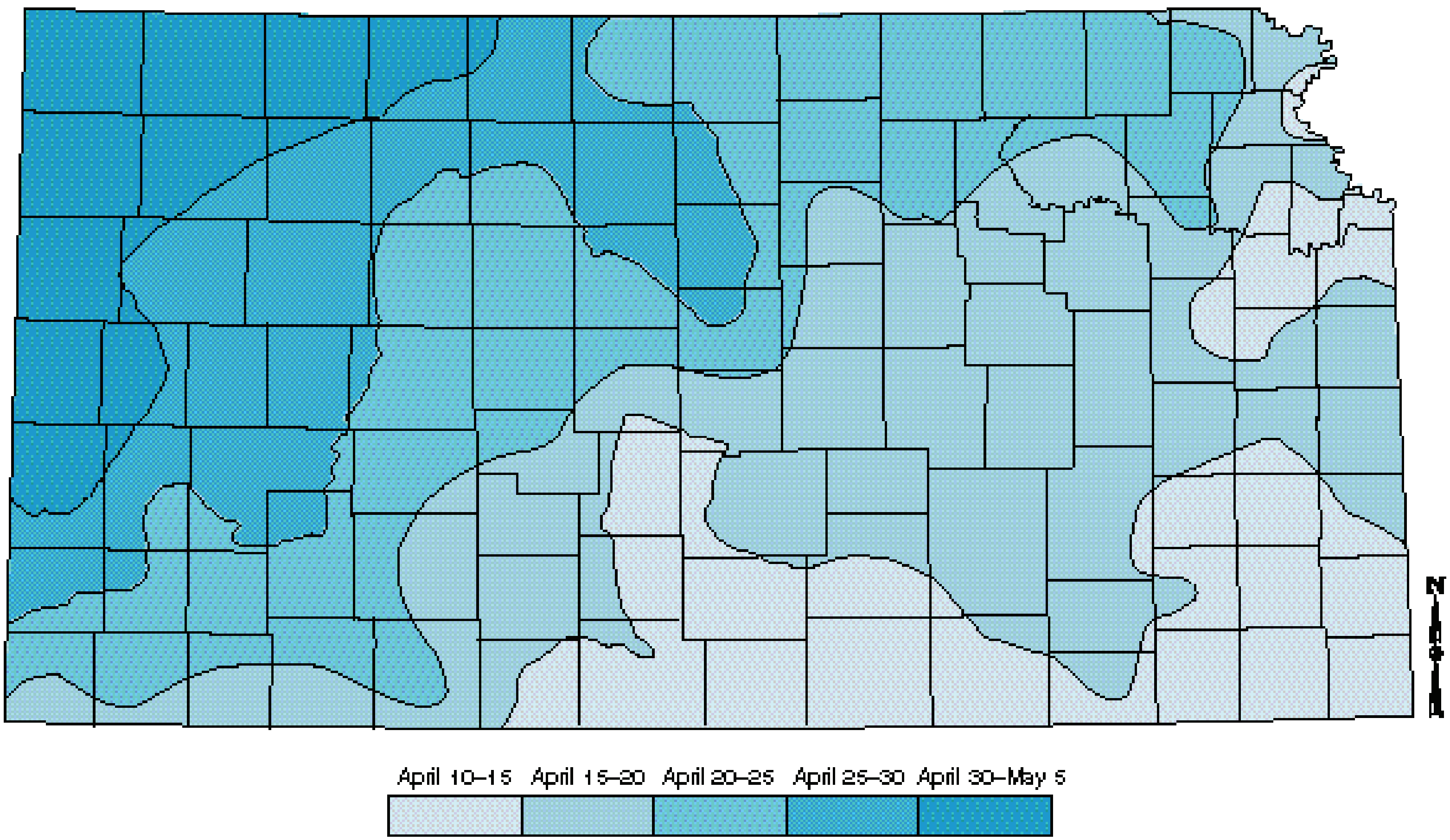


Average Annual Date of First Freeze

very limited resistance to frost. The agricultural significance of a late frost in the spring can be devastating, because this is the time when most field crops are in the most vulnerable stage of their development. These seedlings have very little resistance to freeze effects, and they can be damaged by freezing, or dried up when soil water is frozen. More mature crops can also be damaged by freezing, resulting in reduced yields or even loss of the crop if the freeze is very severe. Since freeze-control measures, such as those used for orchard crops, are not feasible for field crops like the ones produced in Kansas, farmers must be very careful to plant their crops at the proper times to minimize the dangers of frost.

Gardeners also need to know freeze dates when planning their gardens. Most ornamental plants are very susceptible to frost. Vegetable gardens must also be planted after the danger of frost has passed, because germinating seedlings are liable to be killed outright by a freeze unless a cold-resistant variety is used. A planting guide, which lists optimal times for planting, is often included on seed packets. It is important to consider the amount of time a plant requires to mature, so that early fall frosts can be avoided.

In addition to their significance for agriculture and gardening, the dates of first and last freeze are significant for other reasons as well. It is well known that,



Average Annual Date of Last Freeze

unlike most other substances, water expands when it freezes. This simple effect can be observed by placing a half-filled ice tray in the freezer, then observing the ice cubes that form. The cubes will occupy a larger volume than did the liquid water. Water in the soil also expands when frozen, and this can have some serious consequences. If the soil water alternately freezes and thaws repeatedly, a phenomenon called “frost-heave” can occur. Frost-heave can disturb soil and affect plant growth. Large trees are occasionally toppled by the effects of frost-heave. Winter wheat crops can be killed even before they germinate by excessive frost-heave. A similar problem, called frost-wedging, can also occur when water collects beneath roads and sidewalks. Many of the cracks that are visible in roads or sidewalks are the result of numerous cycles of freeze and thaw, occurring over several years. Potholes are a good example of the effects of frost-wedging on heavily used roads. Buildings can also be damaged by frost-wedging, particularly when the building is built of stone and contains numerous cracks or crevices in which water can collect and freeze. The longer the frost season in a year, the greater the hazard of freeze damage. Comparing the two maps of average first and last freeze dates gives the length of both the “frozen” and “frost-free” portions of a typical year. Of course, the ground will probably not be continuously frozen the entire period between the two frost dates. Substantial periods of frozen ground can be expected, however.

The pattern of first and last freeze dates shown on the maps is similar to the temperature maps shown on pages 7–13; however, there are some significant differences. As expected the average date of last freeze occurs earliest in the southeastern portion of the state and latest in the northwest, but topographical variation also influences the pattern. Most of us are familiar with the variation in the amount of sunlight received through a north-facing vs. south-facing window in a house. Topography affects the surface in a similar way, allowing some slopes to receive more solar energy and heat up more, while others receive less. Areas not affected by topography receive solar energy much more uniformly and therefore have a longer frost-free period. For example, look at the average date of the last freeze in Butler, Greenwood, and Elk counties, and then compare it to other counties at the same latitude such as Kingman or Woodson. The counties located in the Flint Hills (Butler, Greenwood, and Elk) experience their last freeze after the two counties located in less hilly terrain. A most unusual circumstance occurs in central Kansas, where Stafford County experiences its last freeze about three weeks earlier than northern Ellsworth County (part of the Smoky Hills), only 50 miles away.

The average annual date of first freeze also reflects the effects of both temperature gradient and topography. Once again, the Flint Hills clearly stand out as a region where first freeze occurs earlier. Parts of Dickinson, Geary, and Morris counties, located in the heart of the Flint Hills, freeze on average three weeks earlier than southern Rice County, a relatively flat area. Again, this is a distance of only about 50 miles, and only a very slight change in latitude. The big difference is the topographic setting. The more gradually changing terrain in western Kansas results in a much more uniform pattern than in the east.

While the information shown on these maps is valid for any location, it is important to bear in mind how very small changes in topographic setting can have significant effects on freeze dates. Thus, a site located on the south side of a hill in the Flint Hills may experience first frost later (and last frost earlier) than a location on the northern side of the same hill. These maps are not designed to show variation at these smaller scales, but such small-scale variations should be kept in mind when deciding where to locate field or garden plots.

Glossary

Air Mass A large body of air characterized by homogeneous physical properties at any given altitude.

Anemometer An instrument that measures wind speed. Usually, it consists of three or four cups mounted on crossarms that spin in response to moving air.

Annual Mean The average of twelve monthly means.

Atmosphere The gaseous portion of the planet.

Climate A description of aggregate weather conditions.

Cloud A dense concentration of ice crystals or suspended water droplets.

Daily Mean An average for a day obtained by averaging the 24 hourly readings or by averaging the daily low and high.

Freezing A change of state between liquid and solid matter.

Front A boundary separating air masses of differing properties. A *Cold Front* is a boundary with advancing cold air. A *Warm Front* is a front with advancing warm air.

Humidity A general term describing moisture in the atmosphere.

Meteorology The study of atmospheric phenomena, especially over shorter time periods.

Monthly Mean A mean determined by averaging the daily means.

Normal The average value of a meteorological element over a fixed period of years, usually recognized as standard. In the United States, 30-year normals are frequently used.

Precipitation Water in some form which falls from the atmosphere. Can be in the form of liquid (rain or drizzle) or solid (snow, hail, sleet).

Thermometer An instrument for measuring temperature. There are several types of thermometers; some measure maximum or minimum temperature.

Station Locations and Names

KS	10	ABILENE 2 W
KS	69	AETNA 2 S
KS	135	ALEXANDER
KS	195	ALTA VISTA
KS	201	ALTON 6 ESE
KS	264	ANTHONY
KS	313	ARKANSAS CITY
KS	365	ASHLAND
KS	405	ATCHISON
KS	424	ATLANTA
KS	431	ATTICA 6 WNW
KS	439	ATWOOD 2 SW
KS	443	AUBURN 1 N
KS	471	AXTELL
KS	532	BARNARD
KS	673	BELLAIRE 12 N
KS	682	BELLEVILLE
KS	693	BELOIT
KS	800	BIG BOW 2 S
KS	836	BIRD CITY 10 S
KS	865	BISON
KS	877	BLAINE
KS	911	BLUE RAPIDS
KS	957	BONNER SPRINGS
KS	1003	BREMEN
KS	1057	BROOKVILLE
KS	1141	BURDETT
KS	1202	BUSHONG
KS	1233	CALDWELL
KS	1351	CASSODAY
KS	1371	CAWKER CITY
KS	1383	CEDAR BLUFF DAM
KS	1395	CEDAR VALE
KS	1408	CENTRALIA
KS	1425	CHALK
KS	1427	CHANUTE FAA AP
KS	1435	CHAPMAN
KS	1522	CIMARRON
KS	1536	CLAFLIN
KS	1559	CLAY CENTER
KS	1593	CLIFTON
KS	1699	COLBY 1 SW
KS	1704	COLDWATER
KS	1730	COLLYER 10 S
KS	1740	COLUMBUS 1 SW
KS	1767	CONCORDIA WSO AP
KS	1795	CONWAY SPRINGS
KS	1858	COTTONWOOD FALLS
KS	1867	COUNCIL GROVE LAK
KS	1875	COVERT
KS	1999	DAMAR
KS	2086	DENSMORE
KS	2135	DIAMOND SPRINGS
KS	2164	DODGE CITY WSO AP
KS	2213	DRESDEN
KS	2267	DUNLAP 2 N
KS	2388	EFFINGHAM 1 N
KS	2401	EL DORADO
KS	2409	ELGIN
KS	2432	ELKHART 6 NNE
KS	2452	ELLIS
KS	2459	ELLSWORTH
KS	2470	ELMDALE 10 WNW
KS	2478	ELMO 1 NW
KS	2519	EMMETT
KS	2592	ESBON 7 N
KS	2602	ESKRIDGE 1 SE
KS	2622	EUREKA
KS	2652	FACT
KS	2773	FLORENCE
KS	2835	FORT SCOTT
KS	2848	FOSTORIA 7 NW
KS	2855	FOWLER 3 NNE
KS	2872	FRANKFORT
KS	2894	FREDONIA 1 E
KS	2975	GARDEN CITY FAA A
KS	2980	GARDEN CITY EXP S
KS	3008	GARNETT 1 E
KS	3037	GENESEO
KS	3074	GIRARD
KS	3153	GOODLAND WSO AP
KS	3175	GOVE
KS	3218	GREAT BEND
KS	3248	GRENOLA 1 N
KS	3257	GRIDLEY
KS	3323	HADDAM
KS	3398	HANOVER 4 S
KS	3432	HARLAN
KS	3467	HARVEYVILLE 3 N
KS	3527	HAYS 1 S
KS	3554	HEALY
KS	3634	HIAWATHA 5 SSE
KS	3667	HILLSBORO
KS	3759	HOLTON
KS	3810	HORTON
KS	3822	HOWARD 5 NE
KS	3837	HOXIE
KS	3842	HOYT
KS	3847	HUDSON
KS	3855	HUGOTON
KS	3930	HUTCHINSON 10 SW
KS	3954	INDEPENDENCE
KS	3974	INMAN
KS	3984	IOLA 1 W
KS	3997	IONIA
KS	4073	JEROME 1 S
KS	4089	JEWELL
KS	4104	JOHN REDMOND LAKE
KS	4161	KALVESTA 1 W
KS	4178	KANOPOLIS LAKE
KS	4313	KINGMAN
KS	4333	KINSLEY
KS	3239	KIOWA
KS	4357	KIRWIN DAM
KS	4421	LA CYGNE
KS	4464	LAKIN
KS	4530	LARNED
KS	4559	LAWRENCE
KS	4588	LEAVENWORTH 4 ESE
KS	4598	LEBANON
KS	4608	LEBO
KS	4613	LECOMPTON
KS	4642	LENORA
KS	4665	LEOTI
KS	4675	LE ROY
KS	4695	LIBERAL
KS	4712	LINCOLN 1 ESE
KS	4735	LINDSBORG
KS	4775	LOGAN
KS	4802	LONGFORD
KS	4807	LONG ISLAND
KS	4812	LONGTON
KS	4821	LORETTA
KS	4857	LOVEWELL DAM
KS	4912	LYNDON 3 ENE
KS	4937	MADISON
KS	4972	MANHATTAN
KS	4982	MANKATO
KS	5039	MARION LAKE
KS	5063	MARYSVILLE
KS	5069	MATFIELD GREEN 2
KS	5115	MC CRACKEN
KS	5123	MC CUNE 6 SW
KS	5127	MC DONALD
KS	5132	MC FARLAND
KS	5152	MC PHERSON
KS	5171	MEADE
KS	5173	MEDICINE LODGE 2
KS	5335	MILTONVALE
KS	5355	MINGO 5 E
KS	5363	MINNEAPOLIS
KS	5463	MORAN
KS	5528	MOUND CITY
KS	5536	MOUND VALLEY 3 WS
KS	5539	MOUNT HOPE
KS	5628	NATOMA
KS	5680	NEOSHO RAPIDS 1 N
KS	5692	NESS CITY
KS	5744	NEWTON 2 SW
KS	5768	NILES
KS	5787	NORCATUR 3 SW
KS	5852	NORTON DAM
KS	5856	NORTON 9 SSE
KS	5870	NORWICH
KS	5888	OAKLEY
KS	5906	OBERLIN
KS	5972	OLATHE 3 E
KS	6014	ONAGA
KS	6076	OSAGE CITY
KS	6084	OSAWATOMIE
KS	6088	OSBORNE
KS	6100	OSKALOOSA
KS	6115	OSWEGO 1 N
KS	6128	OTTAWA
KS	6154	OVERBROOK 2 WSW
KS	6169	OXFORD
KS	6192	PALCO 1 SSW
KS	6209	PAOLA
KS	6217	PARALLEL
KS	6242	PARSONS 2 NW
KS	6305	PECK 3 WSW
KS	6374	PHILLIPSBURG 1 SS
KS	6414	PITTSBURG
KS	6435	PLAINVILLE
KS	6498	POMONA LAKE
KS	6524	POTWIN
KS	6549	PRATT 4 W

KS	6637	QUINTER
KS	6685	RANSOM
KS	6725	READING 2 N
KS	6787	REXFORD
KS	6808	RICHFIELD 1 NE
KS	6813	RICHFIELD 10 WSW
KS	6979	ROSALIA
KS	7007	ROSSVILLE
KS	7046	RUSSELL FAA AP
KS	7049	RUSSELL SPRINGS
KS	7075	SAFFORDVILLE
KS	7093	SAINT FRANCIS
KS	7095	SAINT FRANCIS 8 N
KS	7140	SAINT PETER 4 ENE
KS	7160	SALINA FAA AP
KS	7248	SCANDIA
KS	7271	SCOTT CITY
KS	7305	SEDAN
KS	7313	SEDGWICK
KS	7397	SHARON SPRINGS
KS	7542	SMITH CENTER
KS	7796	STERLING
KS	7809	STILWELL
KS	7832	STOCKTON
KS	7922	SUBLETTE
KS	8038	SYRACUSE
KS	8086	TESCOTT
KS	8114	THRALL 5 S
KS	8156	TONGANOXIE 4 ENE
KS	8167	TOPEKA WSFO AP
KS	8191	TORONTO LAKE
KS	8235	TRIBUNE 1 W
KS	8245	TROUSDALE 1 NE
KS	8250	TROY 4 WSW
KS	8259	TUTTLE CREEK LAKE
KS	8287	ULYSSES 1 SE
KS	8323	UTICA
KS	8341	VALLEY FALLS
KS	8436	VIRGIL
KS	8495	WAKEENEY
KS	8498	WAKEENEY 9 N
KS	8503	WAKEFIELD
KS	8549	WALNUT 3 S
KS	8563	WAMEGO
KS	8578	WASHINGTON
KS	8608	WAVERLY 3 SSE
KS	8648	WEBSTER DAM
KS	8670	WELLINGTON 2 S
KS	8802	WHITE CITY
KS	8830	WICHITA WSO AP
KS	8964	WINFIELD NO 1
KS	8970	WINKLER
KS	8988	WINONA
KS	9040	WORDEN
KS	9080	YATES CENTER
MO	143	AMITY
MO	164	ANDERSON
MO	204	APPLETON CITY
MO	608	BETHANY
MO	1141	BURLINGTON JUNCTION
MO	1145	BUTLER
MO	1356	CARTHAGE
MO	1383	CASSVILLE
MO	1822	CONCEPTION
MO	2474	EDGERTON
MO	2511	ELDORADO SPRINGS
MO	2729	FAIRFAX
MO	3369	GRANT CITY
MO	3568	HAMILTON
MO	3649	HARRISONVILLE
MO	4315	JOPLIN
MO	4358	KANSAS CITY
MO	4505	KING CITY
MO	4705	LAMAR
MO	4850	LEES SUMMIT
MO	5027	LOCKWOOD
MO	5340	MARYVILLE
MO	5704	MONETT
MO	5834	MOUNTAIN GROVE
MO	5862	MT VERNON
MO	5976	NEOSHO
MO	5987	NEVADA
MO	6357	OREGON
MO	6678	PIERCE CITY
MO	6775	POLO
MO	7435	ST JOSEPH
MO	7645	SELIGMAN
MO	8289	TARKIO
MO	8664	WACO
NE	427	ATLANTA
NE	435	AUBURN
NE	520	BARNESTON
NE	640	BEAVER CITY
NE	760	BENKLEMAN
NE	810	BERTRAND
NE	961	BLUE HILL
NE	1240	BRUNING
NE	1415	CAMBRIDGE
NE	1680	CLAY CENTER
NE	2065	CULBERTSON
NE	2306	DEWEESE
NE	2690	ELWOOD
NE	2741	ENDERS LAKE
NE	2820	FAIRBURY
NE	2850	FALLS CITY
NE	2935	FIRTH
NE	3035	FRANKLIN
NE	3175	GENEVA
NE	3485	GUIDE ROCK
NE	3515	HAIGLER
NE	3581	HARBINE
NE	3589	HARDY
NE	3595	HARLAN CO. LAKE
NE	3690	HAYES CENTER
NE	3735	HEBRON
NE	3910	HOLDREGE
NE	4043	HUBBELL
NE	4110	IMPERIAL
NE	4604	LAMAR
NE	5310	MC COOK
NE	5311	MC COOK 16NNW
NE	5388	MEDICINE CREEK
NE	5565	MINDEN
NE	5780	NAPONEE
NE	5840	NELSON
NE	6365	ORLEANS
NE	6480	PALISADE
NE	6570	PAWNEE CITY
NE	7002	RAGAN
NE	7070	RED CLOUD
NE	7110	RED WILLOW
NE	8202	STERLING
NE	8215	STOCKVILLE
NE	8320	SUPERIOR
NE	8410	TABLE ROCK
NE	8465	TECUMSEH
NE	8628	TRENTON DAM
NE	8735	UPLAND
NE	8875	VIRGINIA
NE	9020	WAUNETA
NE	9150	WESTERN
NE	9325	WILSONVILLE
NE	9475	WYMORE
CO	834	BONNY LAKE
CO	895	BRANDON
CO	1121	BURLINGTON
CO	1268	CAMPO
CO	1564	CHEYENNE WELLS
CO	2446	EADS
CO	2932	FLAGLER
CO	2944	FLEMING
CO	3828	HASWELL
CO	4076	HOLLY
CO	4082	HOLYOKE
CO	4242	IDALIA
CO	4388	JOHN MARTIN
CO	4413	JULESBURG
CO	4603	KIT CARSON
CO	4770	LAMAR
CO	4834	LAS ANIMAS
CO	4945	LEROY
CO	6192	OTIS
CO	7515	SEDGWICK
CO	7862	SPRINGFIELD
CO	7866	SPRINGFIELD 7WSW
CO	7992	STONINGTON
CO	8008	STRATTON
CO	9243	WRAY
CO	9295	YUMA
OK	535	BARNSDALL
OK	548	BARTLESVILLE
OK	593	BEAVER
OK	755	BILLINGS
OK	908	BOISE CITY
OK	1243	BUFFALO
OK	1724	CHEROKEE
OK	3250	FORAKER
OK	3304	FORT SUPPLY
OK	3628	GOODWELL
OK	3740	GREAT SALT PLAINS
OK	4019	HELENA
OK	4258	HOLLOW
OK	4298	HOOKER
OK	4393	HULAH DAM
OK	4573	JEFFERSON
OK	4766	KENTON
OK	5045	LAVERNE
OK	5855	MIAMI
OK	6278	NEWKIRK
OK	6935	PAWHUSKA
OK	7201	PONCA CITY
OK	7358	QUAPAW
OK	7534	REGNIER
OK	7556	RENFROW
OK	9203	VINITA
OK	9404	WAYNOKA

Related Readings

The Weather Book. Williams, Jack. Vintage Books. 1992.
This is a readily available publication that provides an easy-to-understand guide to weather and climate in the United States. It includes many graphics, side notes of interesting facts, state-by-state climate information, and a glossary.

Science With Weather. Heddle, Rebecca, and Paul Shipton. Usborne Publishing Co., Inc., NY. 1993.
Filled with scientific activities, this book is designed to help young children learn about the weather. Easily performed experiments include how to measure the wind's speed, how to make a barometer, and how to forecast weather by looking at clouds. This would be of particular use to elementary students.

Simple Weather Experiments with Everyday Materials. Mandell, Muriel. Sterling Publishing Co., Inc., NY. 1990.
A very nontechnical explanation of physical weather, this book provides a number of easily performed experiments. This would be of particular use to elementary students.

Weather in the Lab. Baker, T. R. TAB Books. 1993.
This is a more advanced text geared toward middle school and high school classes. It includes a number of laboratory experiments and includes questions, observations, and post-lab activities. The book also includes a variety of appendices which relate to long-term activities, environmental questions, a materials checklist, sources of equipment, and answers to the laboratory questions.

Meteorology Today, An Introduction to Weather, Climate, and the Environment. Ahrens, C. D. West Publishing Company. 1985.
This is a beginning meteorology text geared toward college students. Includes special focus topics in various areas. It also includes an additional reading list and a glossary of meteorological terms.

Snowflakes. Sugarman, Joan. Little, Brown and Company. 1985.
Easy-to-read text describes how the seemingly infinite varieties of snowflakes are formed. Instructions for catching and preserving the shapes of snowflakes are included in this nontechnical discussion.

Other Publications of Interest Available from the Kansas Geological Survey

Educational Series

Ancient life found in Kansas rocks (common fossils of Kansas), by *R. B. Williams*, 1975, Kansas Geological Survey, Educational Series 1, 44 p.

Kansas rocks and minerals, by *L. L. Tolsted* and *A. Swineford*, revised by *Rex Buchanan* and reprinted 1986, Kansas Geological Survey, Educational Series 2, 64 p.

Kansas clays for the ceramic hobbyist, by *D. A. Grisafe* and *M. Bauleke*, 1977, Kansas Geological Survey, Educational Series 3, 35 p.

Kansas geomaps, by *D. W. Steeples* and *R. C. Buchanan*, revised and reprinted 1984, Kansas Geological Survey, Educational Series 4, 30 p.

From sea to prairie—a primer of Kansas geology, by *C. S. Evans*, 1988, Kansas Geological Survey, Educational Series 6, 60 p.

Petroleum: a primer for Kansas, by *D. L. Baars*, *W. L. Watney*, *D. W. Steeples*, and *E. A. Brostuen*, 1989, Kansas Geological Survey, Educational Series 7, 40 p.

A guide to finding Kansas maps, by *C. S. Evans*, 1990, Kansas Geological Survey, Educational Series 8, 80 p.

Caves in Kansas, by *J. Young* and *J. Beard*, 1993, Kansas Geological Survey, Educational Series 9, 50 p.

Kansas ground water: An introduction to the state's water quantity, quality, and management issues, compiled by *R. Buchanan* and *R. W. Buddemeier*, 1993, Kansas Geological Survey, Educational Series 10, 44 p.

Wichita's building blocks—A guide to building stones and geological features, by *L. H. Skelton*, 1996, Kansas Geological Survey, Educational Series 11, 32 p.

Primer on industrial minerals for Kansas, by *D. A. Grisafe*, 1999, Kansas Geological Survey, Educational Series 13, 32 p.

An atlas of the Kansas High Plains aquifer, by *J. A. Schloss*, *R. W. Buddemeier*, and *B. B. Wilson*, eds., 2000, Kansas Geological Survey, Educational Series 14, 92 p.

A Kansan's guide to science: An introduction to evolution and the nature of science, including origins of the universe and the Earth and the history of life, by *P. Cartwright*, *R. L. Kaesler*, *B. S. Lieberman*, and *A. L. Melott*, 2000, Kansas Geological Survey, Educational Series 15, 19 p.

Also Available:

Roadside Kansas—A traveler's guide to its geology and landmarks, by *R. C. Buchanan* and *J. R. McCauley*, reprinted 1990, University Press of Kansas, 379 p.

Kansas geology—An introduction to landscapes, rocks, minerals, and fossils, ed. by *R. C. Buchanan*, 1984, University Press of Kansas, 212 p.

Land of the post rock, its origins, history, and people, by *G. Muilenburg* and *A. Swineford*, 1975, University Press of Kansas, 221 p.

Geologic highway map of Kansas, 1988, Western Geographics, scale 1:1,000,000 (folded only)

Fossils of Kansas, 2002, by Kansas Geological Survey and KU Museum of Natural History, poster (two-sided), 19 x 23 inches.

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